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OMEGA NORWAY ANTENNA SYSTEM CHARACTERISTICS: MODIFICATION AND V--ETC(U)

MAY 78 A N SMITH, J C HANSELMAN N00123-75-C-0328

UNCLASSIFIED NOSC-TR-246-VOL-3 NL

1 OF 1

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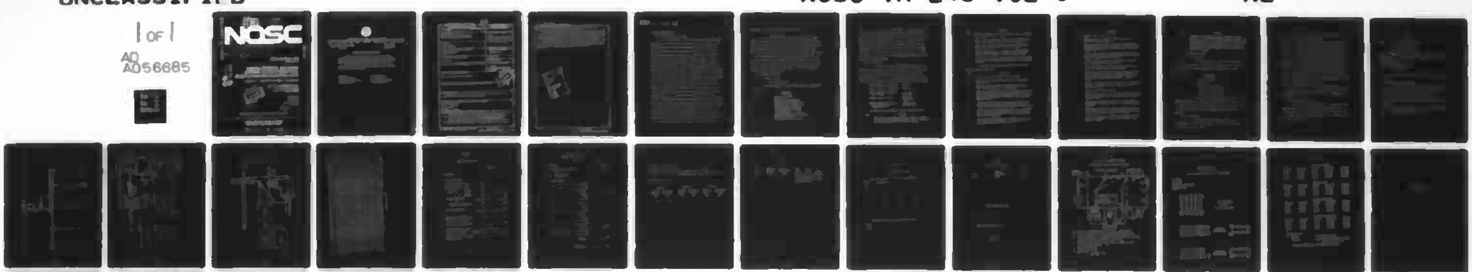

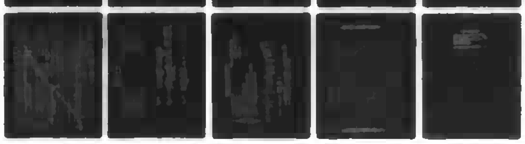

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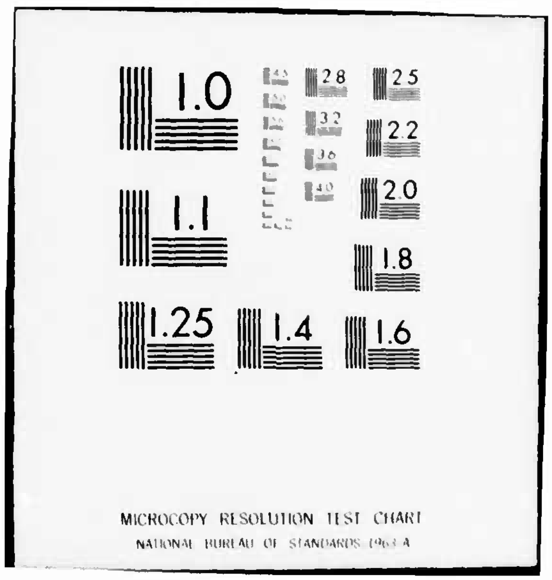
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Technical Report 246
Volume 3

6

OMEGA NORWAY ANTENNA SYSTEM CHARACTERISTICS: MODIFICATION AND VALIDATION TESTS.

Volume 3. Test Plan for Base Impedance.

AD No.
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10 AN Smith ~~NOSC Code 8112~~
JC Hanselman ~~Megatek~~

11 8 May 1978

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12 30p.

NAVAL OCEAN SYSTEMS CENTER
SAN DIEGO, CALIFORNIA 92152

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AN ACTIVITY OF THE NAVAL MATERIAL COMMAND

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HL BLOOD
Technical Director

ADMINISTRATIVE INFORMATION

Electronic measurements were performed on the Bratland Omega Antenna System during the months of July and August 1977. The work was performed under NOSC project MP01537B10 with Megatek as contractor under NOSC Technical Agreement 7220-90, Contract N00123-75-C-0328.

Volume 1 of NOSC TR 246 is the report proper. Volume 2 contains data sheets. Volume 3 is the test plan for base impedance. Volume 4 is the test plan for field intensity measurements.

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WE RICHARDS, Head
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Volume 1 is the report proper. Volume 2 contains data sheets. Volume 3 is the test plan for base impedance. Volume 4 is the test plan for field intensity measurements.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Omega vlf navigation system
Antennas – configuration
Monopole antenna
Measurements – electrical
Radiation resistance – efficiency

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Electronic measurements were performed on the Bratland Omega Antenna System during the months of July and August 1977. The work was performed under NOSC project MP01537B10 with Megatek as contractor under NOSC Technical Agreement 7220-90, Contract N00123-75-C-0328.

The antenna height had been significantly lowered in 1975, therefore tests were conducted on antenna performance in three configurations, so that a curve of performance for each frequency of operation is now available as a function of antenna span height. A determination of geometry by means of an optical

survey was carried out by NOSC in the period 21 through 25 July 1977. Reference data for future comparison, in the event the antenna spans are raised, are thus available.

The electrical height of the antenna is 205 meters for 10.2 kHz when the span is in the so-called 1975 or intermediate elevation in which spans 1 and 3 are respectively paid out 14 and 10½ turns from the "high" or 1973 position. The effective height varies directly as the mean span height, so that the percent increases are the same for electrical and geometrical height. For the 1973 position the effective height is 229 meters. There is a small frequency variation which is very nearly proportional to the fifth root of the frequency ratio.

The antenna system efficiency in the 1975 configuration is 5.9%, and in the 1973 configuration is 7.3%; therefore with 150 kW antenna system input power the station will be able to radiate 10 kW when the spans are raised. For this mode of operation the spans are operating at about 70% of their design voltage limit or less; full 10 kW radiated can be obtained by raising the spans back to the full 1973 height.

1.0 BASE CHARACTERISTICS

1.1 Description of Requirements

1.1.1. The antenna for a VLF transmitting station operating on the OMEGA frequencies (10.2 kHz to 13.6 kHz) is electrically very short and is conveniently, but not accurately, represented by a small inductance, a large capacitance and a small resistance in series. The net reactance, at the operating frequencies, is capacitive. Measurements of the base reactances are made in terms of "apparent capacitance," ($C_{app.}$), by the substitute or auxiliary capacitor method. Since the reactance at the exit bushing is the value required to calculate the tuning network reactance, measurements are made at this point on all the OMEGA and unique frequencies. These values include the net reactance of the bushing and the net reactance of the antenna, expressed as an "apparent capacitance." The tuning network must supply a reactance, of the opposite sign, to resonate the antenna system. The tuning network consists of the Helix inductance (L_H), the variometer inductance (L_V), the inductance of the buswork and the various leakage inductances of the coupling transformers expressed as the tuning inductance (L_{tune}). The inductance of all items except the Helix is measured by substituting a capacitor for everything outside of a variometer room, measuring the resonant frequency and calculating the value of the sum of transformer leakage inductance, the buswork and the variometer. If the variometer is repositioned, to many points in it's operating range, the inductance range of the variometer is obtained. The mid point of the relatively linear portion of the variometer is chosen as the optimum operating point and the total inductance is called L_V. From these values the Helix

inductance (L_H) required is obtained by subtraction:

$$L_H = L_{tune} - L_V$$

1.1.2. Measurements of the self-resonant frequency (f_o) of the antenna are made to determine the approximate values of the static capacitance (C_o) and the inductance of the structure. These approximate values are determined, by calculation, as if they were lumped into a single capacitance and a single inductance. Since both inductance and capacitance are in fact distributed along the structure, the calculation will show a variation depending on the frequency, below self-resonance, used in the calculation. Any variations of C_o as indicated by variation of the self-resonant frequency, caused by aeolian forces, are used to estimate the required travel of the variometer.

1.2 APPARENT CAPACITANCE

1.2.1. Instrumentation

a. Test Equipment List

The following equipment is used in the measurement of Apparent Capacitance.

EQUIPMENT

Oscillator, H-P 651
Counter, H-P
Amplifier, McIntosh MC-100
Resistor "Z" (see Appendix I)
Variable Inductor, 2.2 to 25 mH
Decade Capacitor, G-R-1419B
Variable Capacitor, GR-1422N
Current Transducer, Pearson
Oscilloscope, H-P
Digital Voltmeter, Fluke 8600A
Auxilliary Capacitors, Mica, 0.05 mF
Knife Switch, DPDT
Transformer, Isolation, Topaz

b. Since this is a completed station it is impractical to measure the apparent capacitance and self-resonant frequency from the top of the Helix coil framework as done during the station installation. A table to support instruments similar to Figure 1, will be placed on the roof of the helix building near the exit bushing. The test equipment was connected as shown in the block diagram of Figure 2. An isolation transformer, if used, is placed on the platform, at the end of an extension cord, to provide power for the A.C. operated test equipment without producing a second ground path.

1.2.2. Procedure

a. Since the G-R type 1419-B Decade Capacitor has a maximum voltage limitation of 350 volts rms (500 V peak) it is necessary to limit the current through the resonant circuit of Figure 2 when the substitute capacitors are in use. The following parameters are given to illustrate the procedure used to measure and monitor the current flowing:

Lowest estimate of C apparent:	>0.025 μF.
Lowest frequency of measurement:	>5000 Hz.
Highest reactance of measurement (C app):	<1275 ohms
Highest voltage across C:	<350 V rms 500 V peak
Maximum voltage from Pearson Current Transducer (0.01 V./A.)	<0.0027 V rms 0.0039 V peak

To calibrate the oscilloscope, use the following procedure:

Step	Procedure
1	Connect all the equipment together as shown in Figure 2. Use co-axial cable between the Pearson Current Transducer and the vertical amplifier of the oscilloscope.

Step	Procedure
2	Short the input terminal of the variable inductor to ground using a clip lead.
3	Connect the Fluke 8600A DVM to the Pearson Transducer use-ing a "tee" in the co-axial cable to the oscilloscope.
4	Adjust the gain control of the McIntosh MC-100 amplifier to obtain a reading of 0.0027 V.A.C. on the DVM.
5	Verify that the oscillo[illegible] indication is approximately 0.007 volts peak to peak. Remember this indication of maximum current for future use with Lissajous Figures.
6	Reduce the gain control of the amplifier to zero and remove the clip lead short from the input terminal of the variable inductor.

b. To measure the apparent capacitance of the antenna, the following steps are performed:

Step	Procedure
1	Adjust the Variable Inductor, "L," to maximum.
2	Move the knife switch to the position that connects the antenna to L.
3	Increase the gain control of the amplifier to obtain a small Lissajous figure on the oscilloscope.
4	Sweep the oscillator frequency until resonance is indicated by a sloping straight line figure on the oscilloscope. Adjust the amplifier gain as necessary to keep the vertical component of the picture at, or slightly below, the value found in step a. 5.
5	Increase the horizontal and vertical gain of the oscillo-scope to obtain the largest possible picture with the slope of the line approximately 45 degrees from the vertical.
6	Carefully adjust the oscillator frequency to a value which closes the picture to a straight line. (This indicates that the load, at that point, is at resonance and, there-fore, a pure resistance).
7	Record the frequency reading from the counter on the line for "frequency" on Data Sheet 1. Note that there is a separate sheet for each frequency.

Step	Procedure
8	Reduce the gain of the amplifier.
9	Move the knife switch to the position that connects the variable capacitor package to L.
10	Adjust the capacitor package to produce a straight line. Adjust the amplifier gain as necessary to keep the vertical component of the picture at, or slightly below, the value found in step a. 5.
11	Increase the horizontal and vertical gain to obtain the largest possible picture with the slope of the line approximately 45 degrees from the vertical.
12	Carefully adjust the capacitor package to a value which closes the picture to a straight line.
13	Record the settings of the decade capacitor and the reading of the variable capacitor on data sheets.
14	Sum the corrected values of the decade capacitor settings and the residual capacitance, both taken from Table 1, with the reading of the variable capacitor. Record this value in the column of Table 2, labeled C apparent + bushing.
15	Subtract the bushing capacitance, of 150 pf, from the value in Step 13. Record this value in the column of Table 2, labeled C apparent.
16	Reduce the gain of the amplifier.
17	Repeat Step 2 through 16, for additional frequencies, below the normal operating range, with the following exceptions to Steps 4 and 6: The oscillator frequency is set to a value chosen for measurement. The variable inductor is adjusted to produce resonance.
18	Measurements may be made at several frequencies below the range and must be made at the OMEGA frequencies including the unique frequencies assigned to each station.
19	The value of $X_{C\ apparent}$ + bushing is calculated from the value of C apparent + C bushing and the frequency then entered in Table 2.

Step	Procedure
20	In order to measure $C_{apparent}$ at frequencies lower than resonance of the variable inductor and $C_{apparent}$, additional capacity ($C_{aux.}$ in Figure 2) is added in increments of approximately 0.05 μF. A maximum of 0.15 μF. is recommended if high quality mica capacitors are used. Since $C_{aux.}$ is in the circuit during resonance with both the antenna and the substitute capacitor assembly, the substitute capacitor will read $C_{apparent}$.

1.3 SELF RESONANT FREQUENCY

1.3.1. Instrumentation

a. The following equipment is used in the measurement of Self Resonant Frequency. The variance from those indicated in the test plan may be justified by the avaliability of equipment at the time of test execution.

EQUIPMENT

Oscillator, HP-651

Counter, H-P

Amplifier, McIntosh MC-100

Current Transformer, Pearson

Transformer, Isolation Topaz

b. The same platform and table that was used for the Apparent Capacitance measurements is employed. The test equipment is to be connected as shown in the block diagram of Figure 3. The same isolated power source that was used for the Apparent Capacitance measurements is employed.

1.3.2. Procedure

a. Adjust the oscillator frequency to a frequency well below the expected self-resonant frequency. Set the oscillator output level near one (1) volt r.m.s.

b. Adjust the amplifier gain to produce some small amount of current as indicated on the oscilloscope.

c. Sweep the oscillator frequency up to the first point of resonance indicated by a Lissajous figure showing zero (0) phase angle.

d. Adjust the amplifier gain high enough, within the capability of the equipment, to override noise or interferring signals.

e. Adjust the oscilloscope X and Y gain controls to provide the largest picture possible with the sloping straight line, of the Lissajous figure, at approximately 45 degrees from the vertical.

f. Carefully adjust the frequency of the oscillator to produce a straight line Lissajous figure, then read the frequency from the counter and record the value. Repeat the adjustment of frequency and record the values several times to produce a list that may be averaged. These values are summarized in Table 3.

g. If the wind is blowing, preferably at a variable speed and direction, follow the peak to peak excursions of resonant frequency and record them in Table 3, for an estimate of the variometer travel to be expected.

1.3.3. Calculation of C_0 and L_0

a. In the calculation of the static capacitance and inductance of the antenna it is convenient to assume lumped components. It can be shown that the apparent capacitance at a low frequency and the self resonant frequency may be placed in the following equation to derive the static capacitance:

$$C_o = C_{app}\left[1 - \left(\frac{\omega}{\omega_o}\right)^2\right]$$

where: C_o = Static (D.C.) Capacitance

C_{app} = Apparent Capacitance at ω

ω_o = Self resonant frequency.

A graph of apparent capacitance and the derived C_o is given in Figure 4. Extrapolation of the two curves to zero frequency will help refine the calculated value of C_o.

L_o is derived from the expression:

$$L_o = \frac{1}{\omega_o^2 C_o}$$

C_o, L_o and the calculations necessary to derive these values are shown in Table 4.

1.4 ANTENNA SYSTEM RESISTANCE, R_{as}

1.4.1. The procedure for performing this measurement has been previously reported as the "Incremental Voltage Method for Antenna System Resistance, (R_{as}). The method is described in Appendix I.

1.4.2. The actual resistor (Z) may be one of two available. In either case the value of R will be corrected for frequency to become the impedance "Z".

1.4.3. Measurements will be made at the four (4) OMEGA frequencies and the remaining unique frequency if applicable.

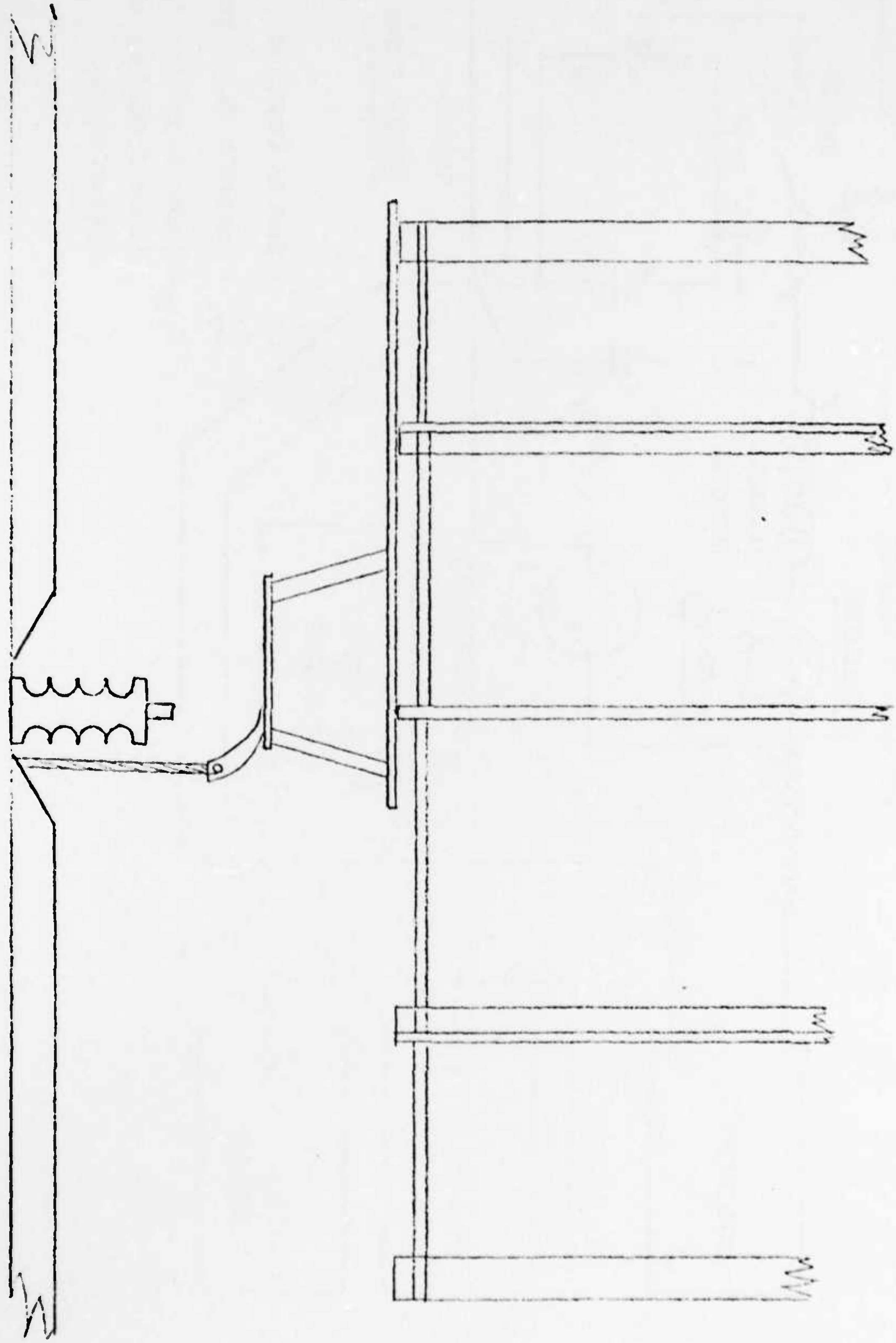


Figure 1

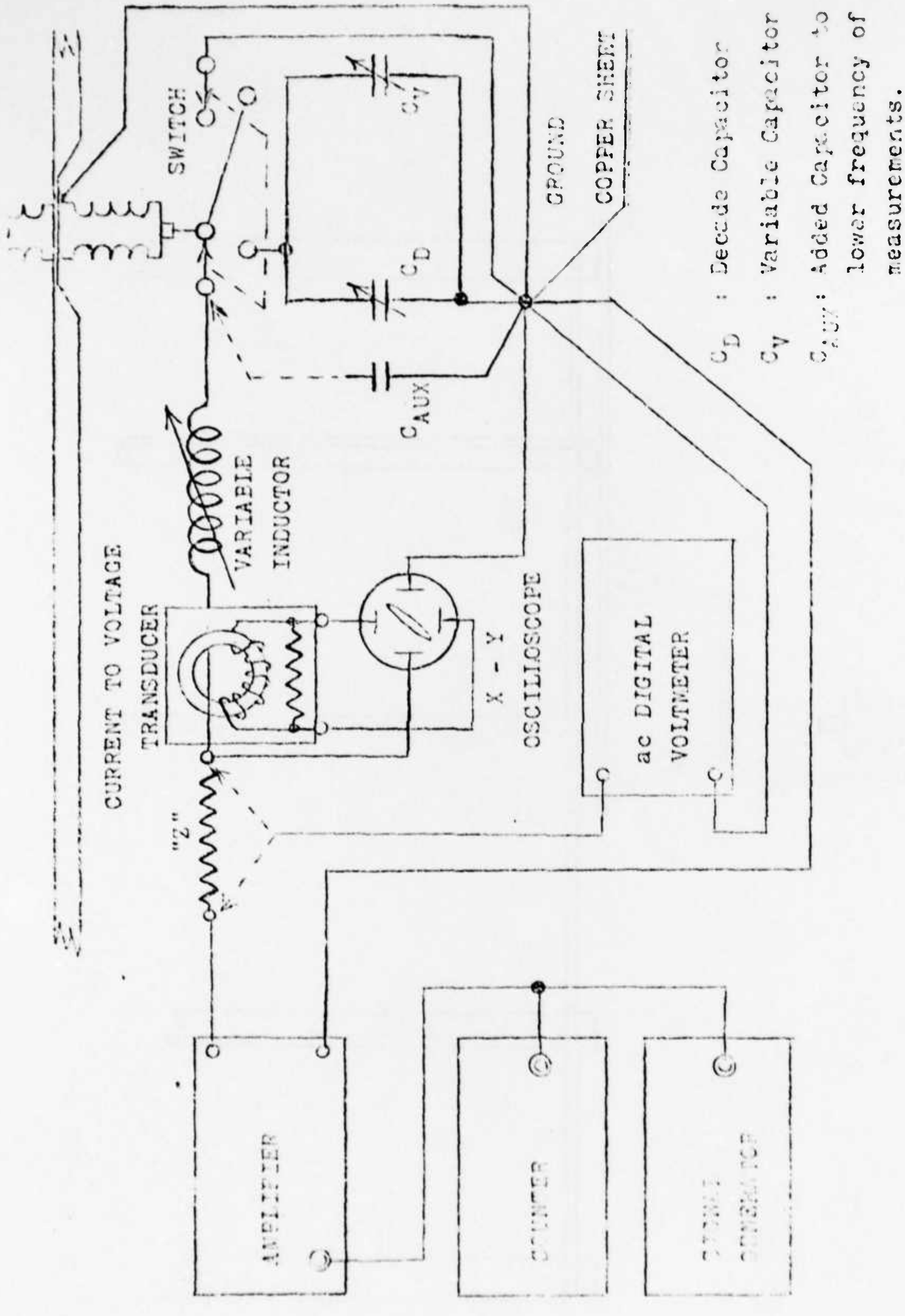

CURRENT TO VOLTAGE
TRANSDUCER
VARIABLE
INDUCTOR
SWITCH
C_V
C_D
C_{AUX}
GROUND
COPPER SHEET
X - Y
OSCILLOSCOPE
ac DIGITAL
VOLTMETER
"Z"
AMPLIFIER
COUNTER
SIGNAL
GENERATOR
C_D : Decade Capacitor
C_V : Variable Capacitor
C_{AUX}: Added Capacitor to lower frequency of measurements.

Figure 2

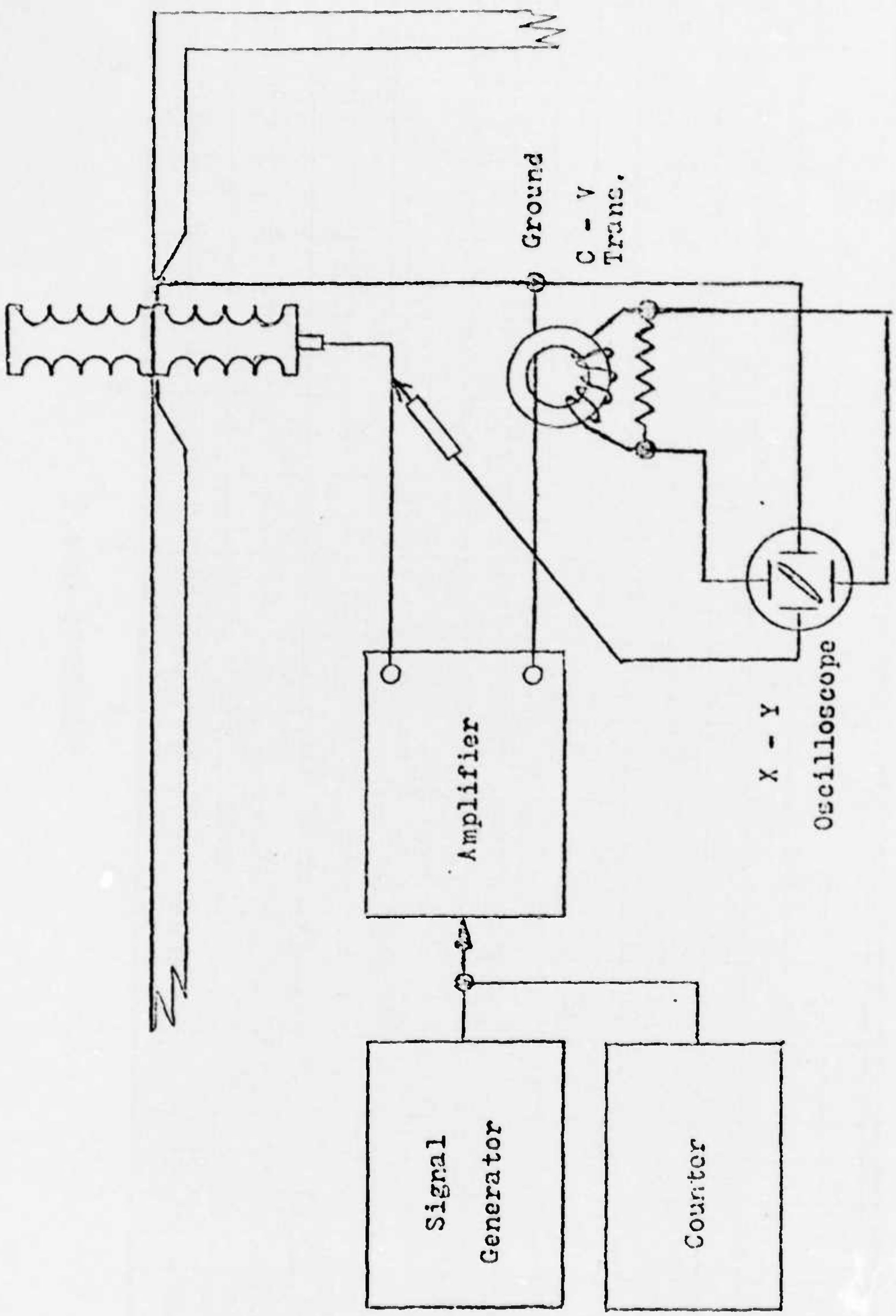

Ground
C - V
Trans.
Amplifier
X - Y
Oscilloscope
Signal
Generator
Counter

Figure 3

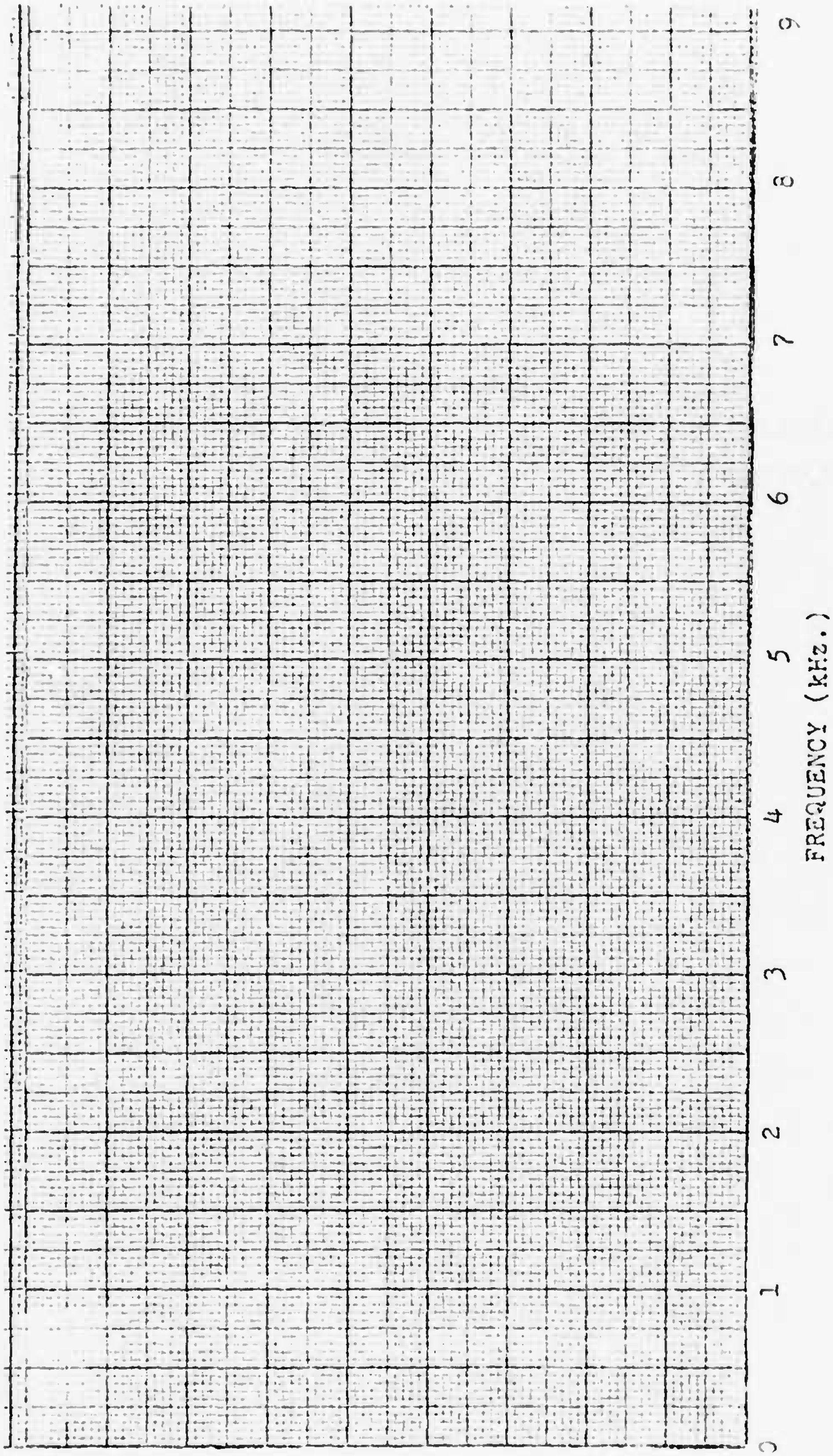


Figure 4

DATA SHEET 1

APPARENT CAPACITANCE

____
Date

1. Frequency ____________________ Hz.

2. Decade Capacitor

   Indicated Reading: 0 . __________ µF.

   Corrected Values : 0.0X 0 . __________ µF.

   (Table 1) 0.00X 0 . __________ µF.

   0.000X 0 . __________ µF.

   Residual Capacitance: 0 . __________ µF.

   Add ____________________

   TOTAL Decade Capacitance: 0 . __________ µF.

3. Variable Capacitor: 0 . __________ µF.

   Add ____________________

4. Apparent Capacitance, $C_{app.}$: 0 . __________ µF.
   (Includes Exit Bushing)

5. Reactance, X_C (Calculated) ____________________ Ohms

6. Exit Bushing Capacitance 0 . 0 0 0 1 5 0 µF.
   (Manufacturer's Data) Subtract ____________________

7. Apparent Capacitance, $C_{app.}$' 0 . __________ µF.
   (Antenna only)

DATA SHEET 2

ANTENNA SYSTEM RESISTANCE

R_{as} ______________ Date

1. Frequency ____________ Hertz
2. Fixed Resistor, Z (Impedance) ____________ Ohms
3. $R_{as} = \frac{E_1 Z}{E - E_1}$ (Ohms)
4. Voltage Readings:

Trial 1
E = _____ . _________ Volts
E_1 = _____ . _________ Volts
$R_{as(1)}$ = _____ . _________ Ohms

Trial 2
E = _____ . _________ Volts
E_1 = _____ . _________ Volts
$R_{as(2)}$ = _____ . _________ Ohms

Trial 3
E = _____ . _________ Volts
E_1 = _____ . _________ Volts
$R_{as(3)}$ = _____ . _________ Ohms

Trial 4
E = _____ . _________ Volts
E_1 = _____ . _________ Volts
$R_{as(4)}$ = _____ . _________ Ohms

Trial 5
E = _____ . _________ Volts
E_1 = _____ . _________ Volts
$R_{as(5)}$ = _____ . _________ Ohms

5. Average R_{as} = _____ . _________ Ohms

TABLE 1

Polystyrene Decade Capacitor

General Radio, Type 1419-B

Serial Number (Unknown) Calibration data supplied by NAVELEXSYSENGCEN, Great Lakes, Ill.

Residual Capacitance:

DECADE 1		DECADE 2		DECADE 3	
Switch Dial uF	Corrected Value uF	Switch Dial uF	Corrected Value uF	Switch Dial uF	Corrected Value uF

TABLE 2

FREQUENCY (Hz.)	$C_{apparent}$ + bushing (uF)	$C_{apparent}$ antenna only (uF)	R'_{as} (Ohms)	R'_{tune} (Ohms)	R_a (Ohms)
——	——	——	R'_{as} and R'_{tune} too large to measure accurately enough to subtract for R_a.		

TABLE 3

SELF-RESONANT FREQUENCY

a. Taken during clear dry weather and low surface wind.

TRIAL	FREQUENCY (Hz.)	E	E_1	R_a
1	____	____	____	____
2	____	____	____	____
3	____	____	____	____
4	____	____	____	____
5	____	____	____	____
6	____	____	____	____
7	____	____	____	____
$\overline{X}$	____	____	____	____
s	____	____	____	____

b. Largest noted peak to peak excursion during slight wind.

f_{high} ____

f_{low} ____

TABLE 4

C_o, Static (DC) Capacitance

Frequency (Hz.)	$C_{app.}$ Antenna only. (uF.)	C_o (uF.)

ANTENNA INDUCTANCE (L_o)

f_o

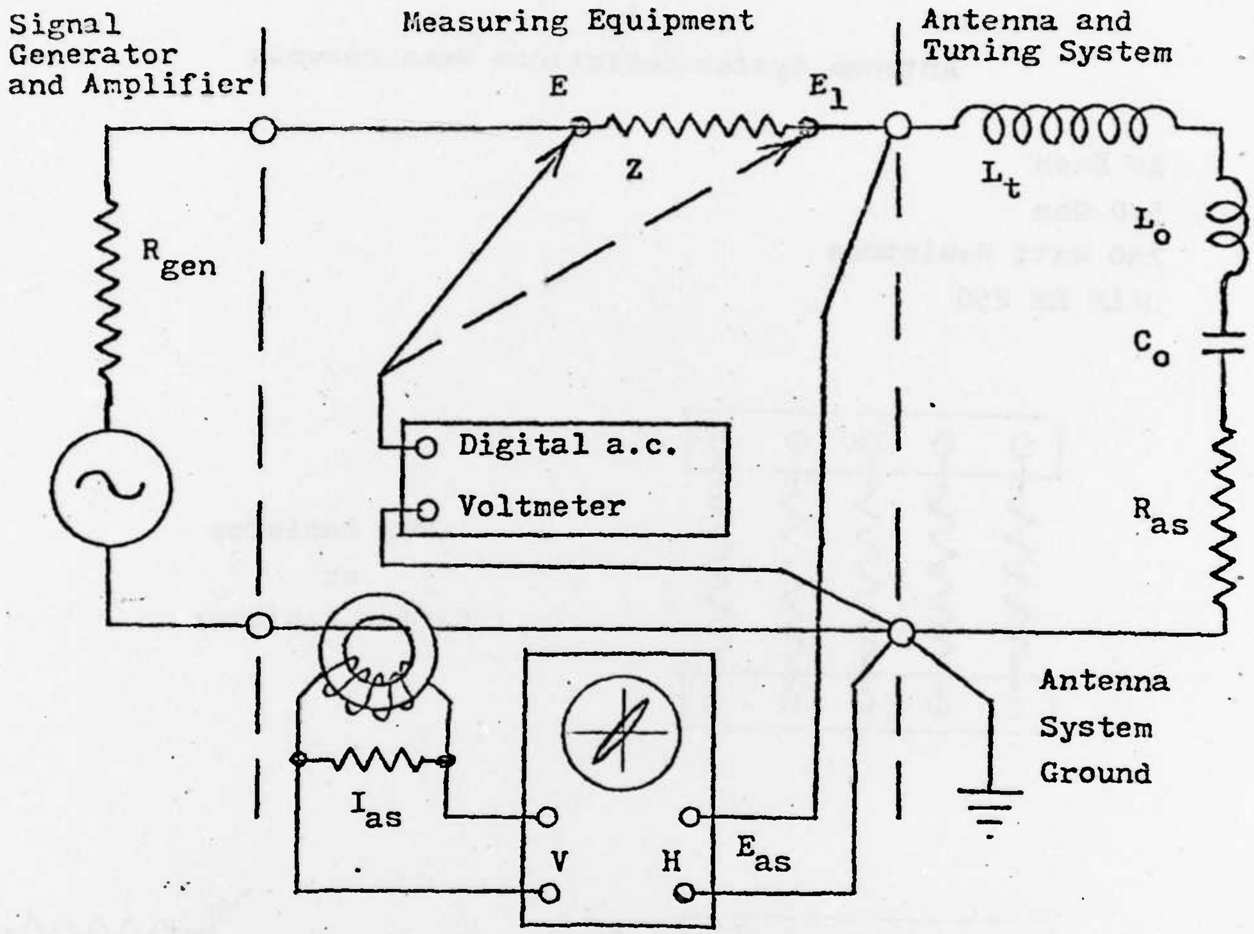
C_o (Extrapolated in Figure 4.)

$$L_o = \frac{1}{(\omega_o)^2 C_o} =$$

APPENDIX I

INCREMENTAL VOLTAGE METHOD

for ANTENNA SYSTEM RESISTANCE (R_{as})



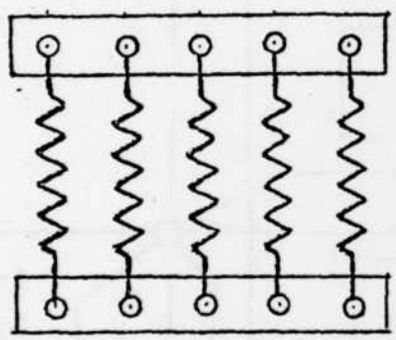
Oscilloscope

1. Select Z approximately equal to R_{as} (Estimated)
2. Set the Generator to the frequency of measurement.
3. Tune the Antenna to resonance as indicated by zero (0) degrees phase angle between I_{as} and E_{as}.
4. Adjust Antenna current (I_{as}) to the maximum value allowable through Z.
5. Measure E and E_1.
6. Solve for: $\frac{E_1 Z}{E - E_1} = R_{as}$

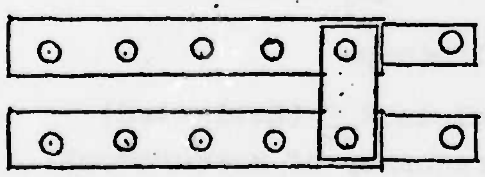
APPENDIX I

Resistor Assembly
for
Antenna System Resistance Measurements

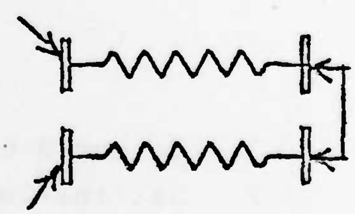
10 Each
5.0 Ohm
250 Watt Resistors
DALE RH 250

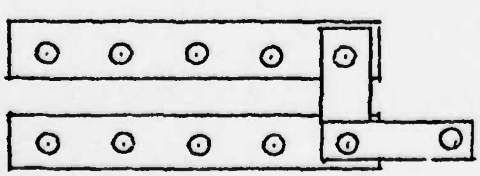


Top Resistor
or
Bottom Resistor

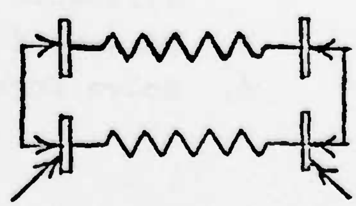


Series
Connection





Parallel
Connection



Bottom Resistor

f(kHz)	R(Ohms)	L(uH)	X_L(Ohms)	Z(Ohms)
10.0	0.993	0.38	0.0239	0.9933
15.0	0.994	0.37	0.0349	0.9946
20.0	0.993	0.37	0.0465	0.9941

Top Resistor

f(kHz)	R(Ohms)	L(uH)	X_L(Ohms)	Z(Ohms)
10.0	0.992	0.36	0.0226	0.9923
15.0	0.993	0.36	0.0339	0.9936
20.0	0.994	0.36	0.0452	0.9950

Series Connection

f(kHz)	R(Ohms)	L(uH)	X_L(Ohms)	Z(Ohms)
10.0	1.984	0.42	0.0264	1.9842
15.0	1.983	0.42	0.0396	1.9834
20.0	1.983	0.42	0.0528	1.9837

Parallel Connection

f(kHz)	R(Ohms)	L(uH)	X_L(Ohms)	Z(Ohms)
10.0	0.496	0.24	0.0151	0.4962
15.0	0.496	0.24	0.0226	0.4965
20.0	0.497	0.24	0.0302	0.4975

MEASUREMENTS:

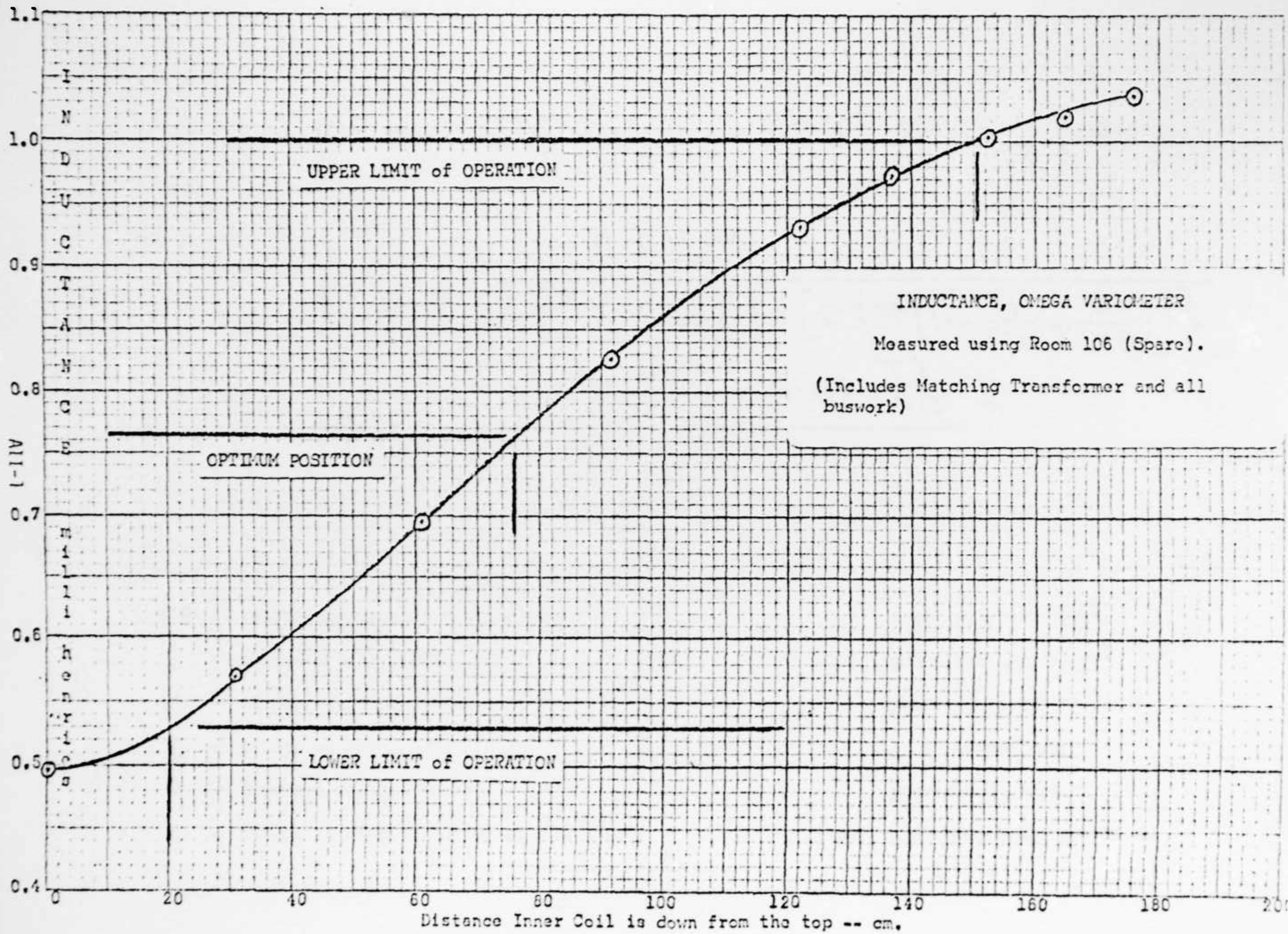
Type: 4 terminal bridge

Bridge: Wayne Kerr, Universal Bridge, Model B221, Mk III

External Generator: H-P 200CD Oscillator

REFERENCE INFORMATION

APPENDIX II



INDUCTANCE, OMEGA VARIOMETER
Measured using Room 106 (Spare).
(Includes Matching Transformer and all buswork)
UPPER LIMIT of OPERATION
OPTIMUM POSITION
LOWER LIMIT of OPERATION
INDUCTANCE millihenries
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0
20
40
60
80
100
120
140
160
180
Distance Inner Coil is down from the top -- cm.

INDUCTANCE EQUATIONS *

C -- center to center spacing of wire (cm.)

d -- diameter of wire (cm.)

ℓ -- length of coil (cm.)

N -- number of turns in the coil

r -- radius of coil (cm.)

L_o -- inductance of coil in free space

* From: "The Theory and Design of Inductance Coils", V. G. Welsby, 1960, Second Edition, p. 42, Equations (40), (41), (42), (43) and (44).

$$K_N = \frac{1}{1 + 0.9\left(\frac{r}{\ell}\right) - 0.02\left(\frac{r}{\ell}\right)^2}$$

$$K_C = 1 - \frac{\ell\left\{\left[\ln 1.73\frac{d}{c}\right] + \left[0.336\left(1 - \frac{2.5}{N} + \frac{3.8}{N^2}\right)\right]\right\}}{\pi r N K_N}$$

$$L_o = \frac{4\pi^2 r^2 N^2}{\ell} K_N K_C \times 10^{-6} \text{ (mh.)}$$

SHIELDING, Effect on Inductance *

b -- radius of shield (cm.)

r -- radius of coil (cm.)

ℓ -- length of coil (cm.)

L_o -- inductance of coil in free space

L_o' -- inductance of coil in a shielded enclosure

ℓ_s -- length of shielded enclosure (along axis of the coil)

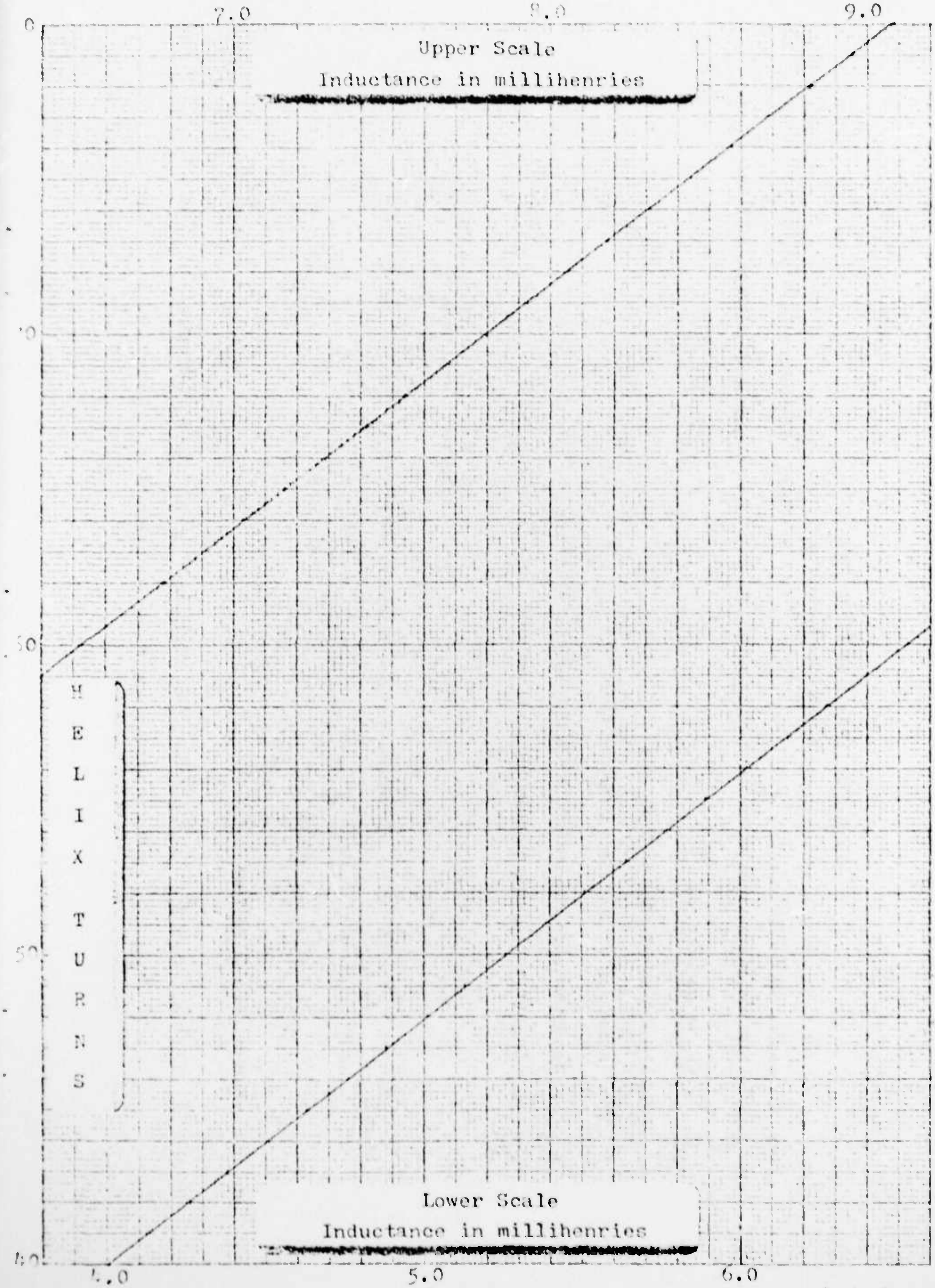
g -- $b-r$ (spacing between coil and shield)

* From: "Radiotron Designer's Handbook", Fourth Edition, p. 439, (D).

$$L_o' = L_o\left\{1 - \left[\frac{1}{1+1.55\frac{r}{\ell}\left(\frac{b}{r}-1\right)}\left(\frac{r}{b}\right)^2\right]\right\}$$

Notes: 1. Valid for: $g/\ell \ngtr 1$

2. When $\ell_s > \ell + 2g$, the effect on L_o' caused by closing the ends of the shielded enclosure is negligible.


7.0
8.0
9.0
Upper Scale
Inductance in millihenries
HELIX TURNS
Lower Scale
Inductance in millihenries
5.0
6.0

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